United States
Department of
Agriculture

Forest Service

**Southern Forest
Experiment Station**

New Orleans,
Louisiana

Research Paper
SO-212
December 1984

Cottonwood Plantation Growth Through 20 Years

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SUMMARY

At age 20 survival of unthinned cottonwood (*Populus deltoides* Bartr. ex Marsh.) planted on medium-textured soil at spacings of 4 by 9, 8 by 9, 12 by 12, and 16 by 18 feet was 10, 17, 30, and 62 percent, and average diameters were 10.6, 11.8, 12.6, and 13.7 inches, respectively. Depending on spacing and diameter threshold, cubic volume mean annual increment peaked at ages 7 to 13. Thinning compared to no thinning reduced cubic volume production. Thinned or unthinned plots of 16- by 18-foot spacing and heaviest thinning at 12 by 12 spacing produced from 340 to 400 board feet per acre per year (Doyle) during the 20 years in trees $\geq$ 12.0 inches to a 10-inch top. Other spacing-treatment combinations provided from 110 to 230 board feet per acre per year.

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INTRODUCTION

Cottonwood is a valuable source of veneer, lumber and pulp and the fastest growing tree species in the South. From 1961 through the mid-1970's, an estimated 40,000 to 50,000 acres of eastern cottonwood (*Populus deltoides* Bartr. ex Marsh.) were planted in the lower Mississippi River Valley (Burkhardt and Krinard 1976); however, the subsequent rate of planting has declined. Generally, initial tree spacings were 9 by 9 or 10 by 10 feet to accommodate traditional farm equipment for first-year mechanical cultivation. At those spacings, trees were expected to reach pulpwood size by the first thinning, require no pruning, and provide adequate stocking if two-thirds of the trees survived.

A study to compare the relationship of diameter and volume growth to initial spacing and basal area control of stocking in cottonwood plantations during the first 10 years (Krinard and Johnson 1975) and the following 5 years (Krinard and Johnson 1980) has been reported. This final paper on the study provides a summary of previous work and additional information through age 20.

METHODS

The study was located on Crown Zellerbach land outside the main Mississippi River levee near Fitler, Mississippi, on medium textured soils, mainly Commerce and Convent silt loams (thermic family of Aeric Fluvaquents). Estimated site indices of these soils, for natural cottonwood stands, range from 105 to 125 feet at age 30 (Broadfoot 1976).

Standard 20-inch unselected cuttings obtained from the Winona State Nursery and the company nursery at Fitler were planted in January 1963 at spacings of 4 by 9, 8 by 9, 12 by 12, and 16 by 18 feet. Plots were about 250 feet square, with a 144-foot square measurement plot centered within each plot. A randomized complete block design with four replications of four spacings and four future thinning treatments were planted; however, losses, primarily to deer, reduced the planting to eight plots per spacing. After the fourth year, plots were arrayed according to basal area within spacings, and thinning treatments were randomly assigned to the four plots with the highest and lowest basal areas.

The study area had been in pasture for many years and was pan-plowed 14 inches deep before planting. Plots were disked during the first year for weed control. After the first year the plots were only mowed in late summer through age 10.

Four thinning treatments were planned to reduce basal area per acre to 40, 65, 90, and 115 square feet whenever these levels were exceeded by 15 square feet. The two plots per spacing to be thinned to 115 square feet never reached that level, were never thinned, and thus served as checks. The two plots each of the 4 by 9 and 8 by 9 spacings were reduced from 105 square feet to 50 square feet, rather than 90 square feet, because experience had shown lack of response to thinning 15+ square feet from basal area levels of 55+ and 80+ square feet.

After 15 years, plots other than the check plots were reduced to 46 trees per acre if they were not already at least to that stocking level. The reasoning was that after 15 years pulpwood was not the major consideration, and the creation of sawlog growing conditions was needed.

Thinning was from below with spacing being the major consideration after removing the obviously weak, poorly formed trees.

For spacings of 4 by 9 and 8 by 9, 55+ to 40 basal area thinnings were initiated at age 4 (average dbh 3.2 and 4.4 inches). The 80+ to 65 basal area thinnings began at age 5 (average

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dbh 3.8 and 5.2 inches). Thinnings were done at 2- to 3-year intervals. The 105+ to 50 basal area thinning was done after the 9th year (average dbh 5.4 and 6.0 inches).

For 12 by 12 spacing, 55+ to 40 thinnings began at age 5 (average dbh 7.0 inches), and the 80+ to 65 thinnings began at age 8 (average dbh 7.9 inches), with from 2 to 4 years between thinnings. The 55+ to 40 thinnings at 16-by 18-foot spacing came at year 7 or 8 (average dbh 9.6 inches) and again at year 10 or 11.

From age 1 through 3, plots were sampled for survival. From age 4 through 20, diameters of all trees taller than 4.5 feet were measured with calipers. Dominant tree heights were randomly sampled after the 4th, 6th, 8th, 10th, 15th, and 20th years.

Sample tree volumes were obtained from cut trees and from standing trees using a Barr and Stroud dendrometer. The tree volumes were then used in constructing local volume tables, with 1-inch dbh classes, for plot volume estimates. Merchantable cubic-foot volume was calculated for volume outside bark in trees ≥5.0 inches dbh to a 4-inch top outside bark. Total volume was stem volume outside bark to a total height for trees ≥2.0 inches dbh. Board-foot volumes were obtained for trees ≥12.0 inches dbh to a 10-inch upper diameter inside bark.

The study had two replications. Statistical comparisons were made among the unthinned plots of the four spacings as they suffered no unusual losses through the 20 years. As some thinned plots were lost to storm damage, no other statistical analyses were made.

RESULTS AND CONCLUSIONS

Figures 1 through 9 show trends over time for check plots by spacings for survival, dbh, basal area, and cubic- and board-foot volumes. Tables 1 through 4 provide 20-year average diameters and total basal areas and volumes by spacings for residuals, mortality, and thinnings.

Generally, the results show closer spacings lead to longer planting times and more cuttings, earlier and greater mortality, smaller average diameters, greater basal area mean annual increment (mai), earlier and greater total volume mai, and less board-foot production.

Specifically, the 4 by 9 spacing yielded many small trees which did not reach merchantability, whether through thinnings or mortality. This spacing may be termed more aptly a fiber or biomass spacing rather than a pulpwood spacing. Utilization of the majority of the trees from the spacing would probably mean using both bark and wood because of small tree sizes involved. Maximum total volume mai was produced, but by only 2 percent more than 8 by 9 spacing on 86 percent more trees. Average diameters of 6 and 8 inches were reached in 12 and 16 years with survival of 40 and 18 percent. With the inherent drawbacks in large tree numbers and small sizes, plus first-year weed control problems because of close spacing (too close for cross disking), the 4 by 9 spacing has little to offer the cottonwood grower.

The 8 by 9 spacing is a pulpwood spacing. Two-thirds and three-fourths of the trees were 5.0 inches dbh or larger at peak mai for total (7th year) and merchantable (9th year) volumes. While maximum merchantable volume mai was produced, it was only 6 percent more than 12 by 12 spacing on 52 percent more trees ≥5.0 inches dbh, plus nearly 80 more trees per acre less than 5.0 inches. Fewer than 50 percent of the cut trees in the heaviest thinning—to favor better trees for potential sawtimber development—had reached 5.0 inches dbh. Doyle board-foot volume mai through 20 years was less than 235 board feet per acre per year. Average dbh's of 6, 8, and 10 inches were reached at 8, 13, and 16 years when survival was 70, 44, and 27 percent, respectively.

The 12 by 12 spacing may be the best compromise of the spacings tried, and considered as either a pulpwood spacing or a pulpwood and sawtimber combination. The maximum merchantable volume mai was only 0.2-cord per acre per year less than the 8 by 9 spacing. The heaviest thinning, where nearly 90 percent of the cut trees were of merchantable size, provided 350 Doyle board feet per acre per year over 20 years. Average diameters of 6, 8, 10, and 12 inches were reached in 5, 9, 14, and 18 years with survival of 79, 75, 60, and 34 percent, respectively.

The 16 by 18 spacing provides a pulpwood-sawtimber combination, producing lowest maximum cubic volume mai's but maximum Doyle board-foot mai (fig. 10). The merchantable volume peak mai was 8 percent less than 12 by 12 spacing and 14 percent less than 8 by 9 spacing in 56 and 137 percent fewer trees. Thinned or unthinned plots produced from 340 to 400 board feet per acre per year—residual plus cut—during the 20 years. Average diameters of 6, 8, 10, and 12 inches were reached in 5, 7, 10, and 15 years, respectively, with survival of 90, 90, 88, and 76 percent.

Spacing influence on diameter and volume growth over time may be analyzed by using the 38 largest trees per acre (to be comparable to

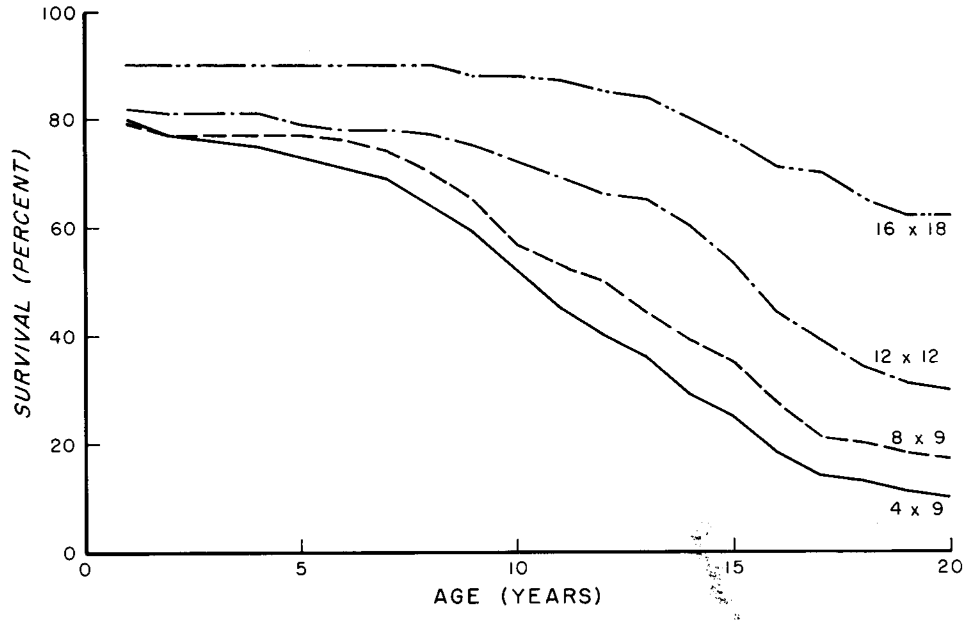

Figure 1.—*Survival of check plots.*

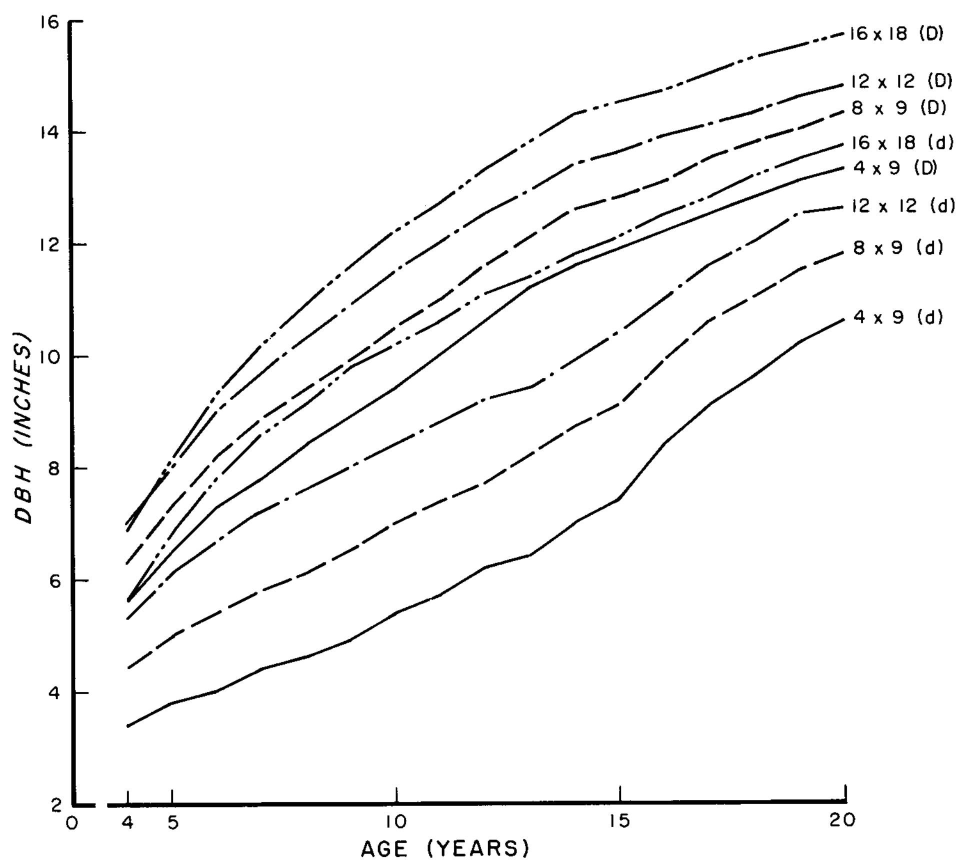

Figure 2.—*Average dbh of all trees (d) and average dbh of largest 38 trees per acre at age 20 (D) in check plots.*

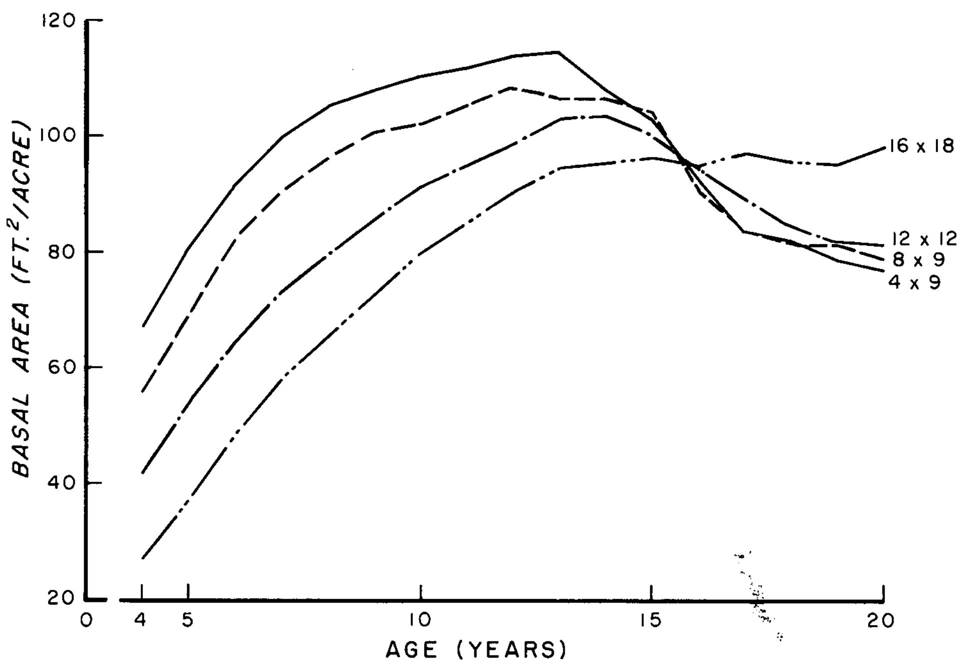

Figure 3.—*Basal area of check plots.*

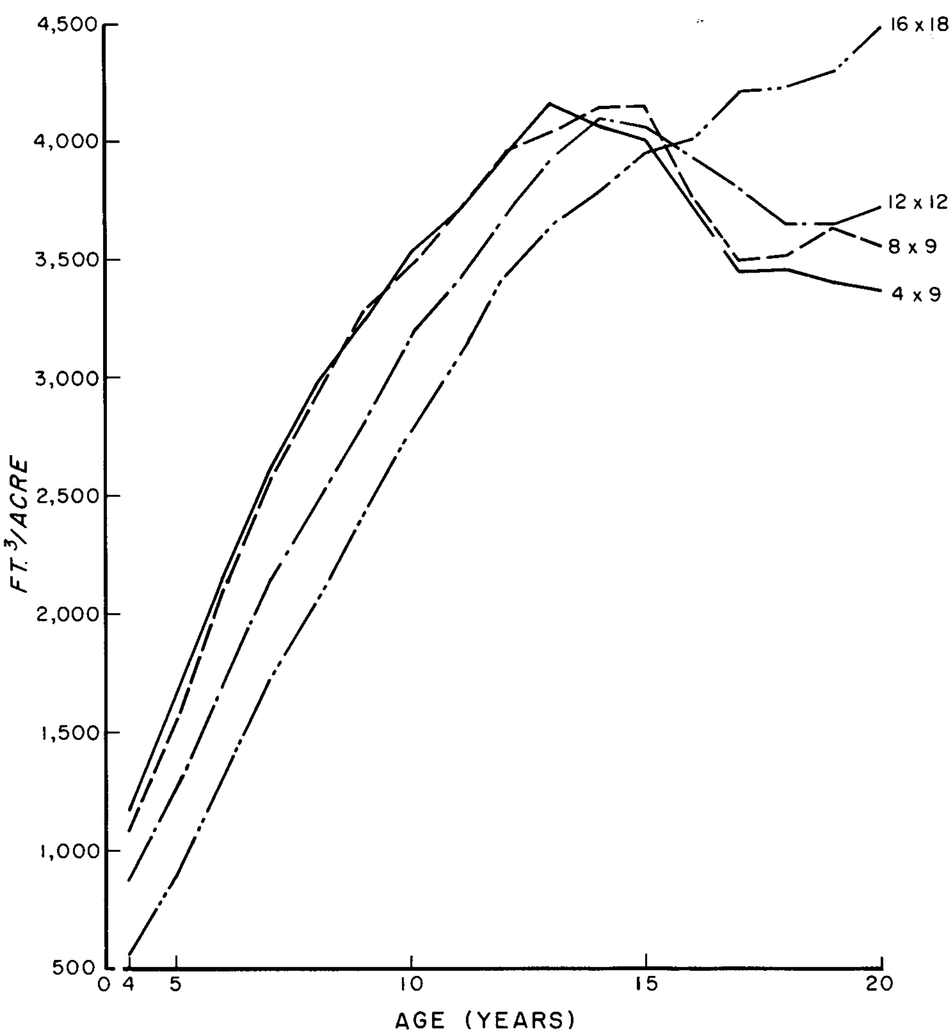

Figure 4.—*Total cubic volume for check plots.*

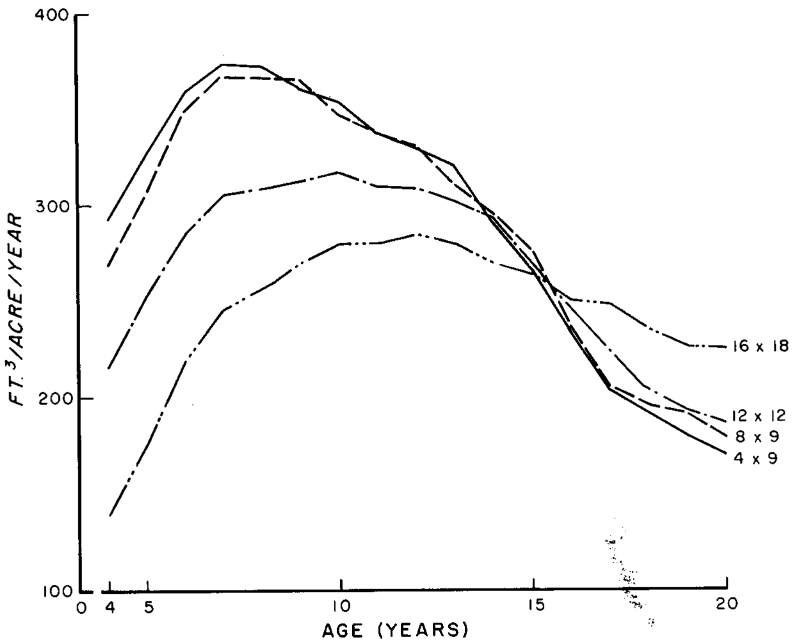

Figure 5.—*Mean annual increment of total cubic volume of check plots.*

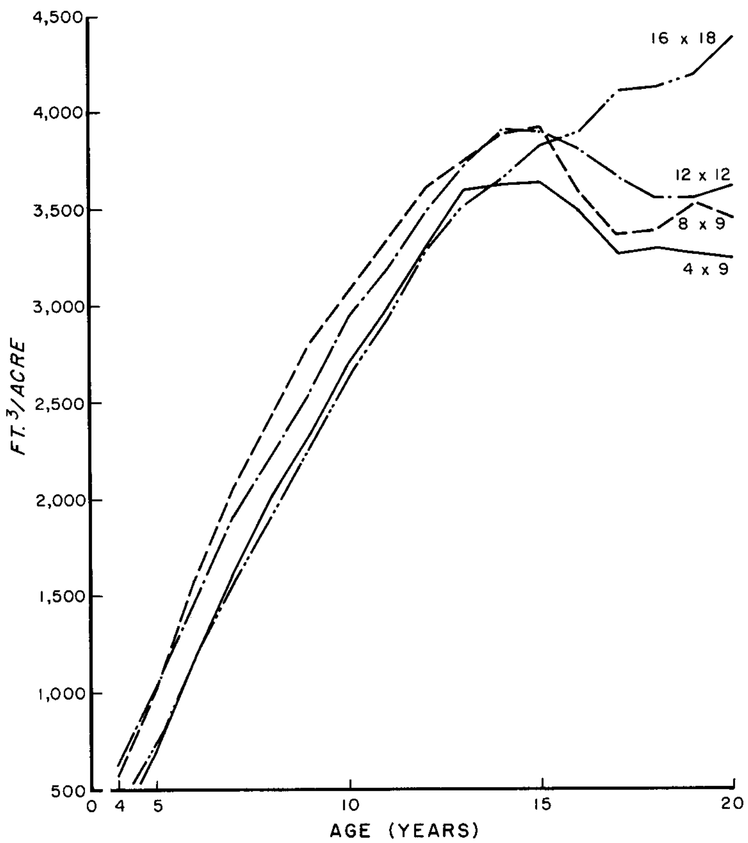

Figure 6.—*Merchantable cubic volume for check plots.*

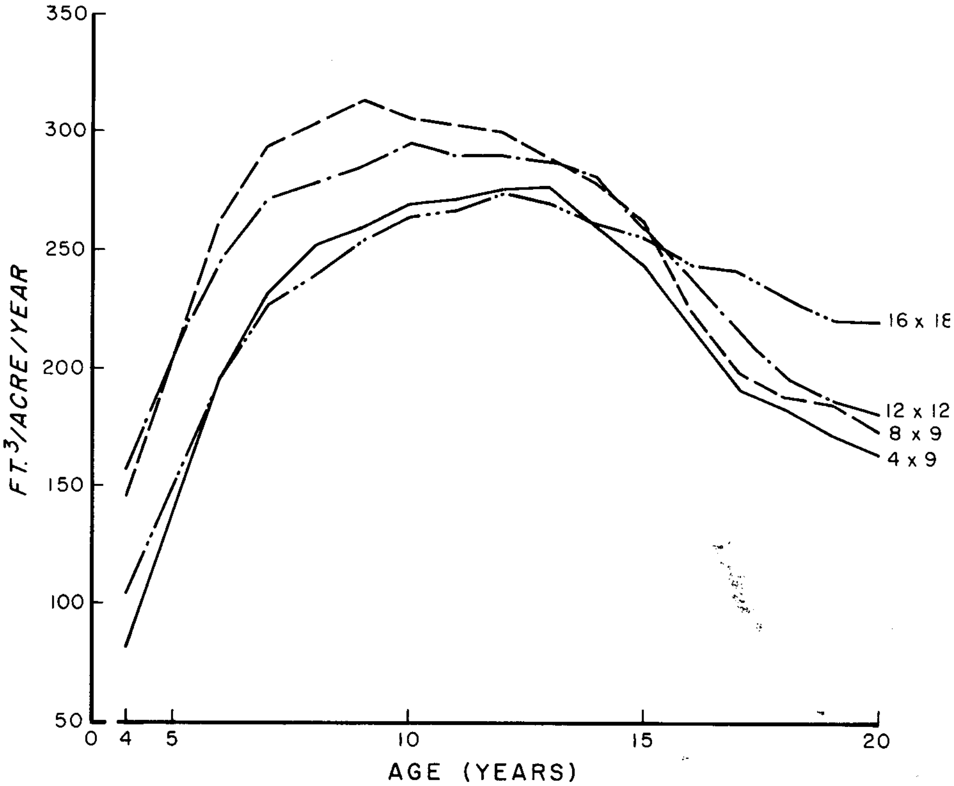

Figure 7.—*Mean annual increment of merchantable cubic volume of check plots.*

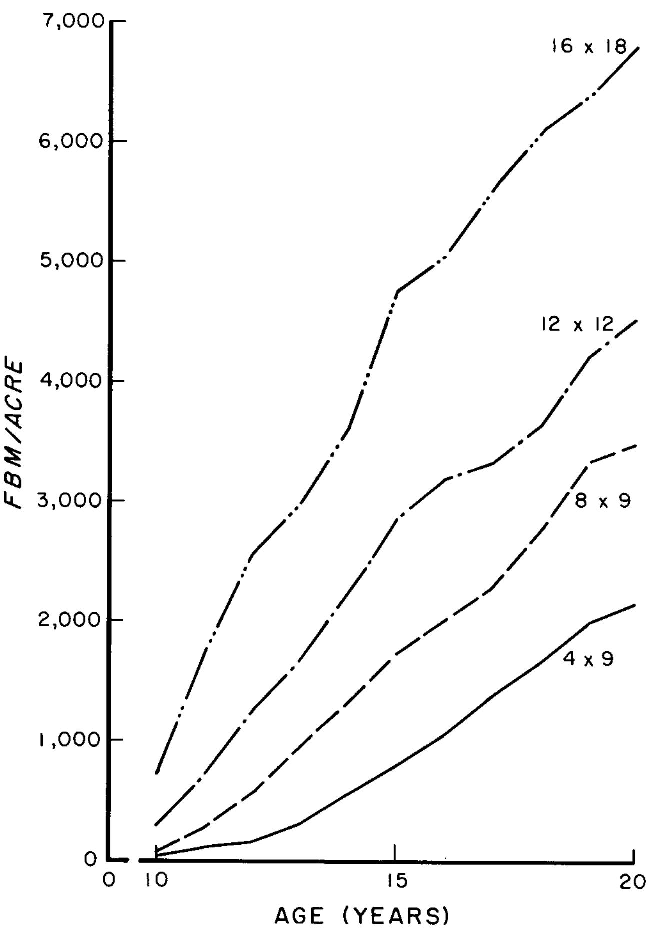

Figure 8.—*Doyle board foot volume for check plots.*

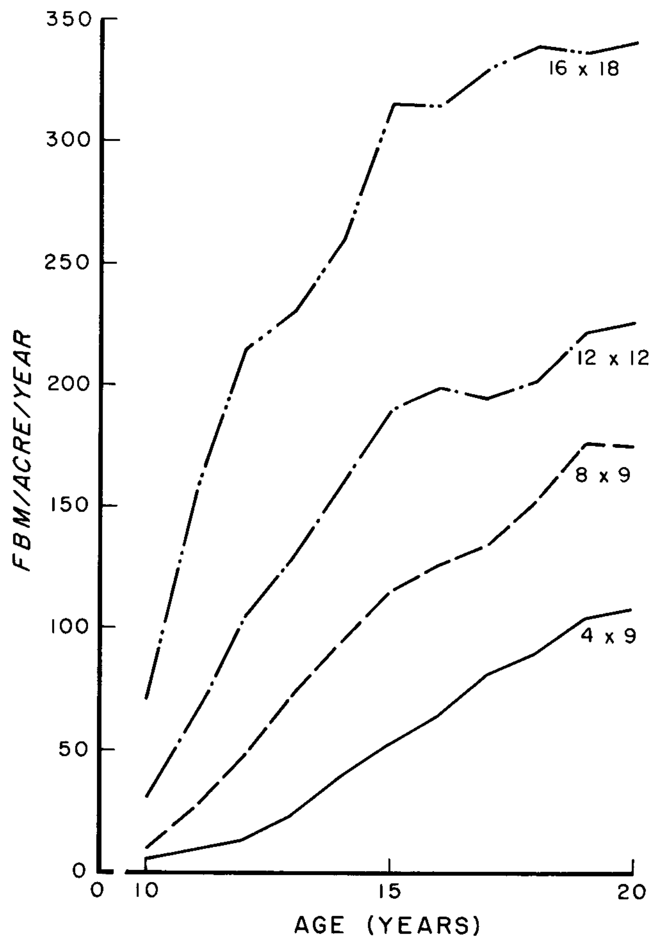

Figure 9.—*Mean annual increment of Doyle board foot volume for check plots.*

Table 1.—*Average dbh by spacings and thinning treatments at age 20*

Spacing	Thinning treatments				
	55+ to 40 ft²/A	80+ to 65 ft²/A	105+ to 50 ft²/A	15[1]	Check
feet	*inches*				
4×9	14.8	13.5	13.9	...	10.6
8×9	14.6	14.6	14.1	...	11.8
12×12	16.5	14.6	...	14.3	12.6
16×18	17.4	...	...	15.2	13.7

[1]Thinned only at age 15 to 46 trees per acre.

Table 2.—*Basal area per acre by spacings and thinning treatments for (1) age 20, (2) thinnings from age 4 through age 15, and (3) mortality from ages 5 through 20*

Spacing	Thinning treatments				
	55+ to 40 ft²/A	80+ to 65 ft²/A	105+ to 50 ft²/A	15[1]	Check
feet	*ft²/acre*				
4×9					
Age 20	46.2	41.3	45.2	...	76.9
Cut	99.3	103.0	95.2	...	...
Mortality	10.4	14.8	21.0	...	86.6
	155.9	159.1	161.4		163.5
8×9					
Age 20	46.7	51.4	50.9	...	79.2
Cut	78.4	96.4	90.4	...	...
Mortality	13.1	7.0	9.7	...	73.0
	138.2	154.8	151.0		152.2
12×12					
Age 20	57.5	50.4	...	44.7	81.6
Cut	58.3	63.6	...	51.2	...
Mortality	13.4	9.5	...	20.3	46.3
	129.2	123.5		116.2	127.9
16×18					
Age 20	61.2	...	...	57.6	98.2
Cut	38.6	...	...	49.4	...
Mortality	6.4	...	...	4.6	20.4
	106.2			111.6	118.6

[1]Thinned only at age 15 to 46 trees per acre.

Table 3.—*Number of trees and volumes by dbh classes and unthinned spacings for age 20 and mortality from ages 5 through 20*

Spacing (feet)	Dbh classes (inches)									
	<2	2-4		5-11		12+		Total		
	N/A[1]	N/A	ft³/A[2]	N/A	ft³/A	N/A	ft³/A	N/A	ft³/A	fbm/A[3]
4×9										
Age 20	...	3.1	8	84.0	1884	32.6	1486	119.7	3378	2168
Mortality	115.6	437.0	676	234.2	2075	...	...	786.8	2751	...
	115.6	440.1	684	318.2	3959	32.6	1486	906.5	6129	2168
8×9										
Age 20	...	2.1	6	55.6	1363	44.1	2193	101.8	3562	3493
Mortality	24.2	130.3	226	210.1	2324	1.0	43	365.6	2593	63
	24.2	132.4	232	265.7	3687	45.1	2236	467.4	6155	3556
12×12										
Age 20	...	1.0	3	34.7	951	54.6	2765	90.3	3719	4521
Mortality	16.8	25.2	41	108.2	1598	4.2	152	154.4	1791	168
	16.8	26.2	44	142.9	2549	58.8	2917	244.7	5510	4689
16×18										
Age 20	...	...	...	21.0	576	72.4	3916	93.4	4492	6832
Mortality	3.2	4.2	9	27.3	482	8.4	321	43.1	812	430
	3.2	4.2	9	48.3	1058	80.8	4237	136.5	5304	7262

[1]Trees per acre.
[2]Cubic-foot volume per acre.
[3]Doyle board-foot volume per acre.

Table 4.—*Number of trees and volumes by dbh classes and spacings-by-thinning treatments for (1) age 20, (2) thinnings from ages 4 through 15, and (3) mortality from ages 5 through 20*

Spacing (*ft*) and thinning (*ft²/A*)	Dbh classes (*inches*) <2	2–4		5–11		12+		Total		
	N/A[1]	N/A	ft³/A[2]	N/A	ft³/A	N/A	ft³/A	N/A	ft³/A	fbm/A[3]
4×9: 55+/40										
Age 20	...	...	...	3.1	99	35.7	2045	38.8	2144	3948
Cut	161.8	647.0	687	198.5	1914	1.0	36	1008.3	2637	38
Mortality	...	...	...	13.6	215	4.2	169	17.8	384	242
	161.8	647.0	687	215.2	2228	40.9	2250	1064.9	5165	4228
4×9: 80+/65										
Age 20	...	...	...	3.1	93	37.8	1765	40.9	1858	2566
Cut	129.2	508.4	637	230.0	2578	2.1	72	869.7	3287	76
Mortality	52.5	11.6	23	29.4	345	4.2	150	97.7	518	164
	181.7	520.0	660	262.5	3016	44.1	1987	1008.3	5663	2806
4×9: 105+/50										
Age 20	...	...	...	5.2	165	36.8	1906	42.0	2071	3164
Cut	13.6	255.2	430	253.2	2664	4.2	150	526.2	3244	176
Mortality	79.8	166.0	178	33.6	348	1.0	44	280.4	570	63
	93.4	421.2	608	292.0	3177	42.0	2100	848.6	5885	3403
8×9: 55+/40										
Age 20	...	...	...	3.1	88	36.8	2076	39.9	2164	3803
Cut	28.4	244.8	318	209.0	1812	1.0	33	483.2	2163	30
Mortality	...	...	...	10.5	245	7.4	264	17.9	509	313
	28.4	244.8	318	222.6	2145	45.2	2373	541.0	4836	4146
8×9: 80+/65										
Age 20	...	...	...	1.0	33	43.1	2360	44.1	2393	4178
Cut	23.1	167.0	239	238.4	2703	8.4	315	436.9	3257	405
Mortality	10.5	3.1	3	14.7	170	2.1	78	30.4	251	95
	33.6	170.1	242	254.1	2906	53.6	2753	511.4	5901	4678
8×9: 105+/50										
Age 20	...	...	...	2.1	55	44.1	2305	46.2	2360	3915
Cut	7.3	139.8	264	251.0	2673	5.2	179	403.3	3116	189
Mortality	9.4	35.7	43	17.8	217	1.0	35	63.9	295	30
	16.7	175.5	307	270.9	2945	50.3	2519	513.4	5771	4134
12×12: 55+/40										
Age 20	...	...	...	1.0	27	35.7	2654	36.7	2681	6768
Cut	3.1	20.0	29	151.3	1470	6.3	228	180.7	1727	338
Mortality	...	...	...	6.3	144	9.4	381	15.7	525	561
	3.1	20.0	29	158.6	1641	51.4	3263	233.1	4933	7667
12×12: 80+/65										
Age 20	...	...	...	3.1	99	39.9	2201	43.0	2300	4022
Cut	3.1	28.4	54	129.2	1909	8.4	356	169.1	2319	594
Mortality	3.1	5.2	7	12.6	265	2.1	83	23.0	355	120
	6.2	33.6	61	144.9	2273	50.4	2640	235.1	4974	4736
12×12:[4]										
Age 20	...	...	...	2.1	66	37.8	2017	39.9	2083	3341
Cut	2.1	2.1	1	105.0	2031	...	...	109.2	2032	...
Mortality	10.5	23.1	29	56.7	525	4.2	156	94.5	710	191
	12.6	25.2	30	163.8	2622	42.0	2173	243.6	4825	3532
16×18: 55+/40										
Age 20	...	...	...	...	...	36.8	2924	36.8	2924	7532
Cut	3.1	3.1	6	55.6	846	12.6	409	74.4	1261	458
Mortality	...	1.0	2	2.1	33	4.2	221	7.3	256	473
	3.1	4.1	8	57.7	879	53.6	3554	118.5	4441	8463
16×18:[4]										
Age 20	...	...	...	1.0	33	44.1	2611	45.1	2644	5114
Cut	...	1.0	3	41.0	853	27.3	1165	69.3	2021	1900
Mortality	4.2	4.2	9	9.4	116	1.0	37	18.8	162	38
	4.2	5.2	12	51.4	1002	72.4	3813	133.2	4827	7052

[1]Trees per acre. [2]Cubic-foot volume per acre. [3]Doyle board-foot volume per acre.
[4]Thinned only at age 15 to 46 trees per acre.

thinned plots) in each unthinned plot after 20 years and comparing growth by 5-year periods. The dbh growth differential between spacings was greatest in the first 5-year period, but the 12 by 12 and 16 by 18 spacings did not differ and were significantly greater (0.05 level) than all other spacing-period combinations. During the second 5-year period, growth of trees at the widest spacing was greater than at the other spacings. Spacings did not influence dbh growth in either the third or fourth 5-year periods. Within spacings, each succeeding 5-year growth period was less than the previous period except the second and third period did not differ at 4 by 9 spacing. From 49 to 55 percent of the 20th-year dbh, depending on spacing, was obtained by year 5.

For the three closer spacings, the upper basal area limits ranged from about 105 to 115 square feet per acre while peak cubic volumes per acre, which occurred from ages 13 to 15, were slightly better than 4000 cubic feet. Basal area—nearly 100 square feet per acre—and total cubic volume—about 4500 cubic feet per acre—were maximum at age 20 for 16 by 18 spacing.

Thinning, as done in this study, tended to reduce mortality if initiated by age 7 and generally gave largest average diameter at age 20 with heaviest thinning. Compared to not thinning, total basal area production—residual, cut, and mortality—was similar or less while cubic volume production was reduced.

Total heights of dominant/codominant trees at age 20 averaged 106 feet for both unthinned and thinned plots. Average height growth over the last 5 years was only 6 feet. Prior growth of tallest trees approximated 12 feet annually the first 4 years, 8 feet annually during the next 4 years, and 3 feet annually for the next 7 years.

This was the first large-scale spacing-thinning study with cottonwood in the Midsouth with a management objective to produce veneer and sawlog size trees along with intermediate products as they occurred on a maximum growth rate basis. A rotation of 30 years was planned. However, at the start of the 21st growing season a windstorm destroyed 120 trees, including some of the largest, and the study was closed. This was the fourth weather-related tree loss, starting with flooding from the Mississippi River in the 11th year and accompanying windthrow and broken stems. Flooding increased incidence of stem canker and possibility of future stem breakage. Although this study may or may not be representative of average storm-related damages, all cottonwood plantings in the batture have the potential for flooding and accompanying problems. Thus, long-term, i.e., sawtimber, plantations on these sites have a built-in risk factor which may decrease yields.

Figure 10.—*Unthinned, 20-year-old cottonwood planted at 16- by 18-foot spacing with 58 percent survival, 13.6 inches average diameter, and 6,600 board feet per acre, Doyle, to a 10-inch top dib.*

Very rapid early diameter and height growth characterize cottonwood plantings, with diameter growth peaking in the third or fourth year regardless of spacing. Cottonwood, if it is to continue rapid growth, cannot tolerate side competition, so wide spacings or early thinnings at close spacings prior to severe competition are needed. Thinnings in this test, which removed too few trees or occurred too late, may have helped maintain growth of residual trees but did not increase growth. There was no observable response of crown growth into created openings. An estimated 40 percent or more live crown ratio is needed for good growth, as measured on dominant and codominant cottonwood in natural stands (Johnson and Burkardt 1976).

The last 5 years of plantation development added nothing to previous conclusions regarding spacings for pulpwood production and for both pulpwood and sawtimber production. To reiterate, 8 by 9 and 12 by 12 spacings are recommended for pulpwood production. Volume mai peaked from the 7th to 10th years, depending on spacing and merchantability limits. For pulpwood production, no thinnings are needed. The 12 by 12 and 16 by 18 spacings appear feasible for producing both pulpwood and sawtimber. A possible method of treating the spacings would involve one or two pulpwood thinnings, taking half the trees at each thinning at about 60 square feet of basal area, to put both spacings at a 24 by 24 spacing. At least one sawtimber thinning, when basal area reaches 80 to 100 square feet per acre, should provide a final crop of about 38 trees with average dbh of 24 inches and 120 square feet of basal area. Rotation age to 24 inches is not precisely known.

In the publication based on the 15-year results of this study (Krinard and Johnson 1980), it was estimated that thinned plots of the two widest spacings might produce 23,000 board feet in 30 years, which would be similar to yields on unthinned natural stands found by Johnson and Burkhardt (1976). The yield prediction assumed an average dbh of 24 inches, merchantable length of 3½ logs, and 40 trees per acre. The 24-inch dbh figure assumed 15- and 16-inch trees would grow 8 to 9 inches in 15 years, or 2.7 to 3.0 inches in 5 years. Unless the ever-decreasing diameter growth rates were reversed—the same trees surviving after 20 years in the thinned plots of the two wider spacings grew 7.9, 3.8, 2.6, and 1.4 inches by 5-year growth intervals—there would be no way for the trees to average 24 inches in 30 years. Even the two plots of the 16 by 18 spacing, which received the heaviest thinning and have been stocked with 42 trees per acre or less since the 12th growing season, only grew 1.5 inches in the past 5 years. The trees have room to grow but do not have the crown development of dominant/codominant trees of natural stands.

An obvious conclusion is that wider initial spacings, with pruning for quality, should be used where a sawtimber rotation of less than 30 years is the objective. Even wider spacing, though taking advantage of very rapid early diameter growth, may not maintain that growth for much longer intervals. For example, diameter growth of unpruned trees at 40 by 40 spacing (27 trees per acre) grew 5.0 inches from age 6 through 10 (unpublished data on file at the Southern Hardwoods Laboratory, Stoneville, Mississippi), but the 27 largest trees per acre in the unthinned 16 by 18 spacing grew 4.2 inches in the same period—less than an inch difference in 5 years. The big difference, though, occurred in the first 5 years when diameter growth of the two spacings was 11.4 (Krinard 1979) and 8.0 inches.

For sawtimber production, is there a spacing which would produce 24-inch trees with two high quality logs in 20 years? Maybe, but unpruned trees in the previously mentioned 40 by 40 spacing which were 16.4 inches in 10 years, were growing 0.8 inch a year in the 8th through 10th years. If that growth could be maintained for 10 years, 24-inch trees would be possible, but limbs would make trees low in stumpage value. As pruning reduces diameter growth, 24-inch trees in 20 years does not appear to be reasonable expectation over large areas. Assumptions, based on extrapolation of growth of existing plantations and known pruning effects on diameter growth, indicate 28 by 28 to 32 by 32 spacing may produce 20-inch trees and 11,000 to 12,000 board feet in 20 years and nearly 25-inch trees and 21,000 to 22,000 board feet in 30 years.

Direct comparisons with European methods are difficult. Although their culture is much more intensive, an average guide for good sites in the Po River Valley in Italy showed 12.5-inch trees in 15 years with 202 trees per acre (about 15-foot spacing) and 18.2-inch trees in 20 years with 96 trees per acre (about 21-foot spacing) (Food and Agriculture Organization of the United Nations 1979).

Wider spacings provide less than full site utilization, require intensive pruning, and the trees are still subject to flooding, wind damage, cankers, and insects. Because of the costs and risks involved, cottonwood from planting may not be suitable for long rotations for some landowners. Either a change in utilization standards, so that smaller trees and shorter rotations are feasible, or higher stumpage values which would justify higher management costs, or different management practices and/or clones, which would sustain early plantation growth, could change that outlook.

The main factors favoring cottonwood plantings are the very rapid early growth and early returns. Negative factors are high plantation establishment costs and, for sawtimber and veneer logs, long-term weather risks, and lack of data on alternative cultural methods and superior clone performance in long rotation management.

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Twenty-year summary of a cottonwood study that compares the relationship of diameter and volume growth to initial spacing and basal area control of stocking.

Additional keywords: *Populus deltoides*, stand development, thinning.